ANALYSIS OF AN ARCHERY BOW USING FINITE ELEMENT METHOD AND THE DEVELOPMENT OF AN ARCERY BOW

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ABSTRACT

In terms of Archer, it has been a well known sport worldwide. Basically, a bow consists of 3 main parts which is the riser, limb and the string. In improving the performance of the bow, it is crucial to research each and every part of the bow. There are many mathematical modelling has been done to improve the performance of the bow but only few analysis and experiments are done. Therefore, the objective of the study is to analyse the Archery Bow using Finite Element Method and to develop the Archery Bow. Two different methods were used before fabricating the bow which is to analyse the stress and strain of the bow drawn in CAD software using FEM software and to test experimentally using the strain gauge method. Validation between the results was used as a reference for fabrication. The best material was chosen by doing a simulation analysis on the composite materials which shows that E fibreglass have the best properties compared to the other fibreglass. Therefore, as for the results, E fibreglass is used to fabricate the limb of the bow so that it will be highly in strength and also in elasticity which is up to 72.4 GPa. The results shows that the fabricated bow have a lower strain which are 0.00244 compared to the current bow which is 0.004694. This shows that the fabricated bow have a higher potential to withstand much higher force compared to the current bow which makes the new bow to have a better quality. As for the error analysis, it shows that the higher force applied to the bows makes the error to increase to the increase in vibration and the damping force.

ABSTRAK

Dari segi sukan memanah, ia telah menjadi salah satu sukan yang terkenal di seluruh dunia. Pada asasnya, sebuah anak panah terdiri daripada 3 bahagian utama iaitu riser, limb dan tali. Dalam meningkatkan prestasi pada sesebuah busur, ia adalah penting untuk mengkaji untuk mengkajinya dengan keseluruhan. Terdapat banyak kajian telah dijalankan dalam bentuk kiraan matematik tetapi hanya beberapa analisis dan eksperimen telah dijalankan untuk menbuktikanya. Oleh itu, objektif kajian ini adalah untuk menganalisa anak panah dengan menggunakan kaedah simulasi dan untuk membuat sebuah anak panah. Dua kaedah yang berbeza telah digunakan sebelum membuat panah tersebut yang terdiri daripada kaedah menganalisis tekanan pada anak panah tesebut yang dilukis di perisian lukisan dan simulasinya menggunakan perisian FEM dan untuk menguji kaji menggunakan kaedah tolok ketegangan. Pengesahan antara keputusan yang telah digunakan sebagai rujukan untuk fabrikasi. Bahan yang terbaik telah dipilih dengan melakukan analisis simulasi bahan-bahan komposit yang menunjukkan bahawa gentian kaca E mempunyai ciri-ciri terbaik berbanding dengan gentian kaca yang lain. Oleh itu, sebagai untuk keputusan, kaca gentian E digunakan untuk membina anggota badan bagi anak panah tersebut supaya ia mempunyai kekuatan dan juga keanjalan yang baik sehingga 72.4 GPa. Keputusan menunjukkan bahawa busur direka mempunyai tekanan yang lebih rendah iaitu 0.00244 berbanding busur semasa yang 0.004694. Ini menunjukkan bahawa busur yang baru direka mempunyai potensi yang tinggi untuk menahan kuasa yang lebih tinggi berbanding dengan anak panah semasa yang membuat anak panah baru untuk mempunyai kualiti yang lebih baik. Bagi analisis ralat, ia menunjukkan bahawa kuasa yang lebih tinggi memjadikan nilai ralat semakin meningkat kerana peningkatan dalam getaran dan daya ketegangan.

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LIST OF SYMBOLS

A	Cross sectional area
P	Pressure
E	Modulus of Elasticity
a	Acceleration
m	Mass
t	3-Dimensional drawing of riser
σ	Engineering stress
ε	Engineering strain
δ	Change in length
v	Poisson's ratio
b	Width
h	Height
N	Newton
ΔR	Difference in resistance
Ω	Ohm (Unit for current)
S_g	Gauge factor

LIST OF ABBREVATIONS

2D	2-Dimensional
3D	3-Dimensional
CAD	Computer Aided Design
FEM	Finite Element Method
FEA	Finite Element Analysis
CSM	Chopped Strand Mat

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In the early days, the invention of bow plays an important role in the history of mankind where it is mainly used for the purpose of war and hunting. Besides that, it is also mentioned as a tool which is used to engage enemies even in a long distance. The bow is a stringed projectile weapon designed to shoot a long and round sharp edged arrow to a target. It consists of a slender stave and a cord fastened to it at each end under a certain amount of tension. The string and the arrow are pulled back until the limbs is bent and then released so that the impelling force of the bow string will shoot the arrow. A bow can store energy as deformation energy in its elastic arms or limbs. Its special feature is that this energy, delivered by the relatively slow human body, can be quickly released to a light arrow in a very effective way. Where, the deformation energy if easily transferred into kinetic energy which couples the bow and arrow. But in the 15th century, archery was superseded in battle fields due to the existence of firearms.

Today in the modern world, archery is mostly used as a competitive sport. It is an important sport which is being played in the summer Olympics. Many countries have taken the initiative to improve the archery equipments so that their athletes could perform better in that tournament.

1.2 PROBLEM STATEMENT

It is true that, in terms of archery bows, there are many improvements that had been made compared to ancient times such as improving the materials specifically the increase in the usage of composites.

"The mechanical properties of the materials of these bows, however are much better than those of the ancient bows. Indeed, the modern bow holds now the longest flight shooting record" (B. W. Kooi, 1991).

"The use of composite materials has allowed this (aerodynamic drag) optimisation while still retaining the required dynamic stiffness for archery performance" (M.Rieckmann, J.Codrington and B.Cazzolato, 2011).

However, there are also many criteria's that need to be considered such as the balancing and the efficiency of the limbs, the archer and the whole performance of the recurve bow itself.

"It can be said very definitely that the smoothness of action and absence of kick in a bow, depend primarily on two factors. The first is a dynamic balance of the limbs and the second is that the bow be highly efficient" (B. W. Kooi, 1993).

Many mathematical calculations and experiments have been done regarding the archery bow but only few analysis or computer simulation is done.

1.3 OBJECTIVE

To analyse an Archery bow using Finite Element Method and to fabricate the Archery bow.

1.4 SCOPES OF PROJECT

i) Limited to 3-dimensional (3D) modeling of the Archery bow.
ii) Fiberglass is used as the composite material.
iii) The weight of the bow is limited from 10 to 20 Newton.
iii) Type of Bow used is a Recurve Bow by right handed archers.

1.5 ORGANISATION OF THE THESIS

First chapter of the study shows the basic explanation about archery including with the objective and the scopes of the study. Second chapter is where the literature review is done with doing some comparison between the previous studies which has been done. The third chapter tells the method which is used to conduct the study and the fourth is the part where all the results are shows with discussion. As for the fifth and the final chapter, the conclusion of the total study is shown with some recommendation to improve the current study.

CHAPTER 2

LITERATURE REVIEW

In this chapter, basic knowledge which is related to archery bow will be described. The common types of bow which can be found such as the traditional long bow recurve bow and also the compound bow is described. Besides that, the material which is widely used such as the composites materials has also been explained. Moreover, the fundamental theory which will be used for the fabrication of the bow is also discussed.

2.1 CHARACTERISTICS OF A BOW

A bow is mainly made up of 3 main parts which is the riser, limbs and the string. Riser is the part which is located at the middle which is also called as the grip due to its function. The part which is located on both sides of the riser is called as the limbs. Where, when it is hold vertically, the upper part is called the upper limb whereas the lower part is called the lower limb. A string is fastened at both ends of the upper and lower limbs at a certain amount of force (Kooi, 1983).

The distance between the riser and the string is called as a fistmele. This distance can be changed by changing the length of the string. The belly side is the part of the limbs which faces away from the archer. Normally, there will be nocks at the end of the limb which is used to tie the string at the ends. Nowadays, there is an extra part which is placed in the middle part of the string which is called the nocking point where the arrow can be correctly placed at the point to give an easy and accurate shooting.

As shown in Figure 2.1, a common recurve bow is made of riser, upper and lower limbs, bowstring and the nocking point.

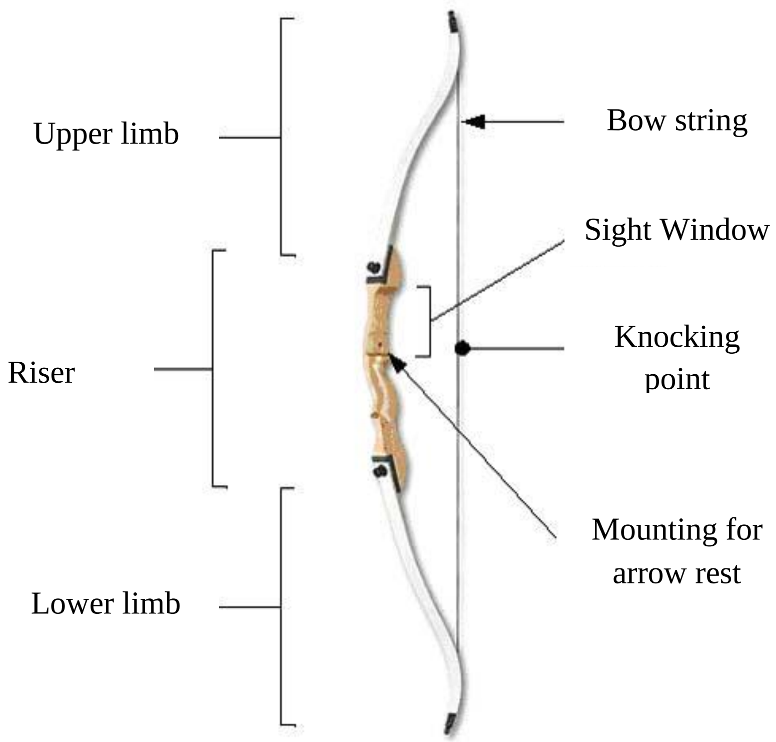

Figure 2.1: Main parts in an Archery bow

Source: Archery resource (2010)

2.2 TYPES OF BOW

Today in the modern world, there are mainly three types of bow which is the traditional longbow, recurve bow and the modern compound bow.

2.2.1 Longbow

Longbow was invented at late thirteenth century. This bow had draw weight of about 445 Newtons to 535 Newtons. Longbows do not put as much energy into the arrow as other bows, which is why they have to be more powerful. In medieval times, draw weights could reach up to 150 pounds. But today longbows generally rarely exceed 50 pounds. They are less accurate and more difficult to shoot than a modern bow. And there are no any rests with a longbow where the archer has to support the arrow by themselves (elyarchers, 2012).

2.2.2 Recurve bows

The side-view profile of the bow which looks like a curvature makes it to be called as a recurve bow. This style of bow stores more energy than an equivalent straight-limbed bow, and therefore gives a greater amount of force to the arrow. By contrast, the traditional straight longbow tends to pull back the extra force, but as for the recurve bow, as the string is drawn further back, the required draw force increases rapidly. The curved limbs also put greater strain on the materials used to make the bow, and they may make more noise as they are shot. A typical modern recurve bow as used by archers in the Olympics and many other competitive events will employ advanced technologies and materials and will have been made by a professional. The limbs are usually made from layers of fibreglass, carbon or wood. Carbon limbs will shoot the arrow faster for a given draw weight when compared with wooden limbs, but they are much more expensive. The riser is generally separate and is normally constructed from aluminium or magnesium alloy. The modern recurve is the only form of bow allowed in the Olympic Games. Recurve archers often have many other pieces of equipment attached to their recurve bows, such as stabilisers which is for balancing the bow and absorbing some of the vibration, sights for improving the accuracy and pressure buttons for a fine tuning of the arrow's flight. A piece of leather called a tab is worn when shooting to ensure a smooth release and save wear on the fingers. The high technology materials of a modern bow allow the manufacturers to make a bow with a better efficiency and also permit the easy attachment of modern aids to accuracy such as the stabilisers. The greater weight of a modern bow is in itself an aid to stability in the grip, and therefore to accuracy (elyarchers, 2012).

When comparing the recurve bow, it can be divided into three which is non-recurve bow, static-recurve bow and the working-recurve Bow (Kooi, 1983).

2.2.2.1 Non-recurve bow

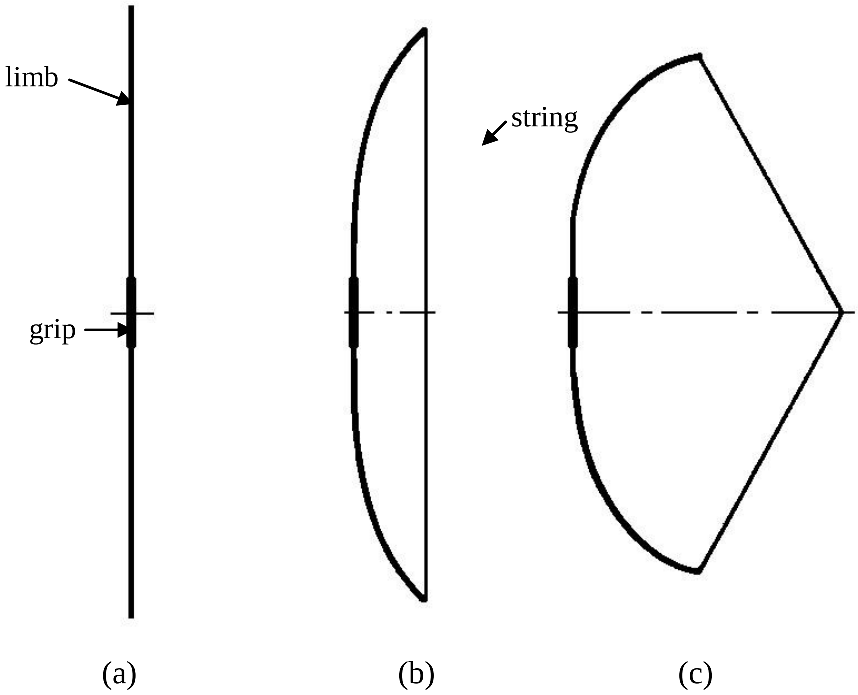

Figure 2.2: (a) unbraced non-recurve bow (b) braced non-recurve bow (c) fully drawn non-recurve

Source: Kooi (1983)

Figure 2.2 shows the non-recurve bow in three different situations which is in unbraced, braced and fully drawn situations respectively. It will only have its curve after a string is attached to the ends of the limbs. The bend tip of the limbs makes it to be curved which makes it to be a recurve bow.

2.2.2.2 Static-recurve bow

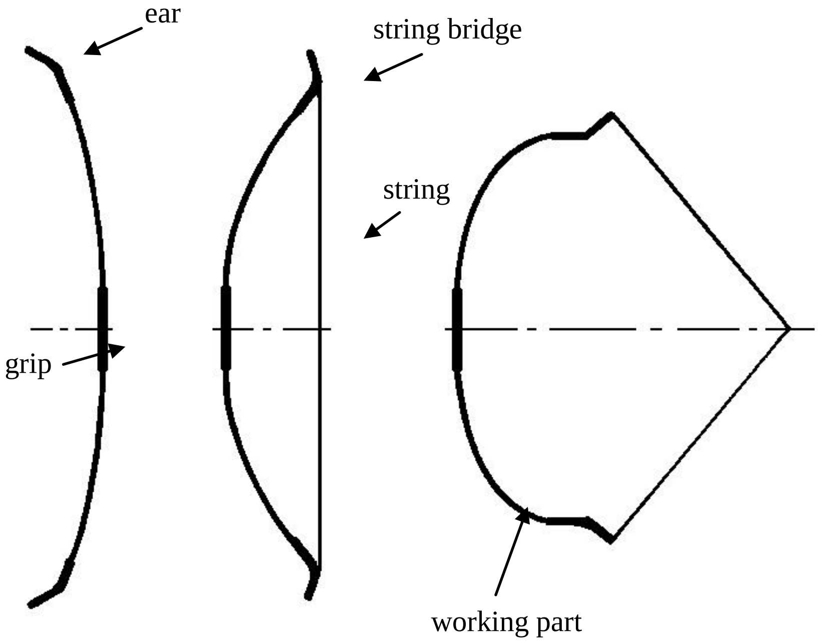

Figure 2.3: (a) unbraced static recurve bow (b) braced static recurve bow (c) fully drawn static recurve

Source: Kooi (1983)

As shown in Figure 2.3, static recurve bow is also shown is three different situations which is unbraced, braced and in the fully drawn situations respectively. The outermost parts of the limbs are stiff. These parts are called ears or rigid-end pieces. The elastic part of a limb between grip and ear is called the working part of the limb. In the braced situation the string rests on the string-bridges, situated at the bend of the ears. These string bridges are hollowed out sometimes, to receive the string and retain it in its place. This prevents the string from slipping beside the limb and giving it a fatal twist. When these bows are about half drawn, the string leaves the string-bridges and has contact with the limbs only at the tips. After releasing at a certain moment before the arrow exit, the string touches the string-bridges again.

2.3.2.1 Working-recurve bow

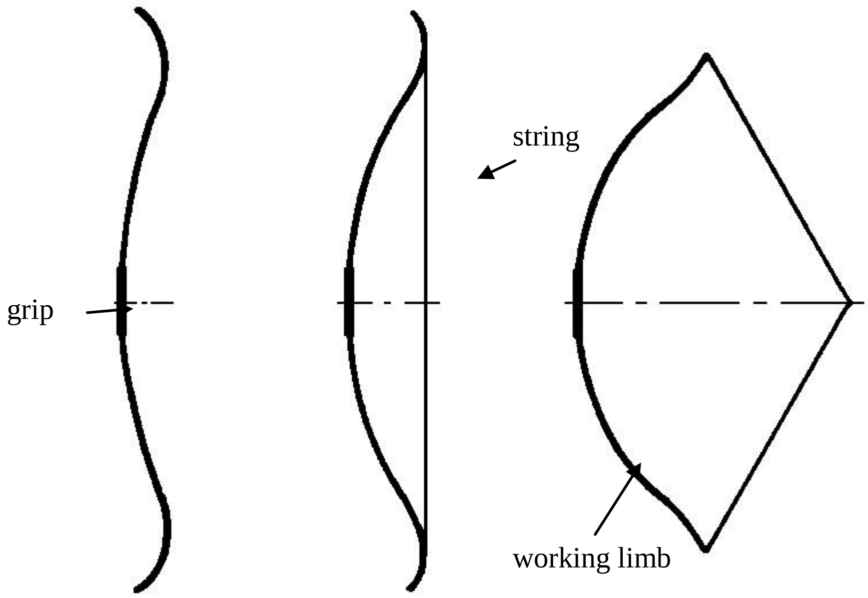

Figure 2.4: (a) unbraced working-recurve bow (b) braced working -recurve bow (c) fully drawn working -recurve

Source: Kooi (1983)

Figure 2.4 shows the working recurve bow in three situations which is in the unbraced, braced and fully drawn situations respectively. In the case of a working-recurve bow the parts near the tips are elastic and bend during the final part of the draw. When drawing the bow the length of contact between string and limb gradually decreases until the point where the string leaves the bow coincides with the tip of the limb and remains there during the final part of the draw. After release the phenomena happen in reversed order to prevent the possibility of a twist of the limbs in the case of a working-recurve bow, grooves are present on the belly side of the limbs starting at the notch and extending sufficiently far in the direction of the grip. We note that bows belonging to each of the three types may be symmetric or more or less asymmetric.

2.2.3 Compound bows

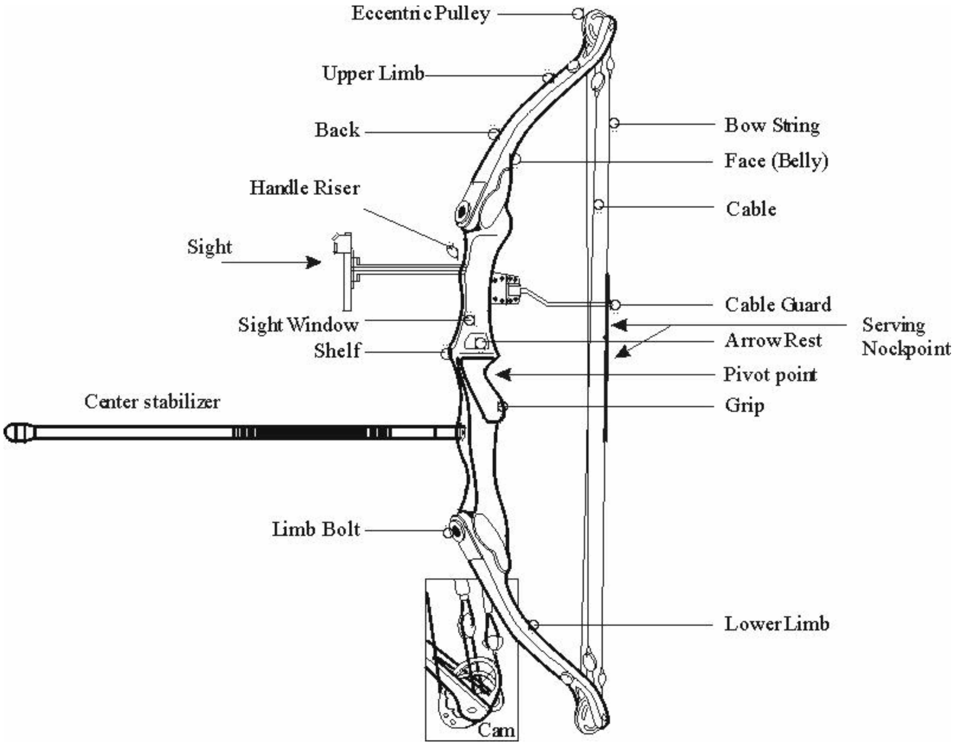

Figure 2.5: Compound bow

Source: METU (2009)

Figure 2.4 shows the picture of a compound bow and the parts in it. A compound bow is a modern development of bow which use a lever system of cables, wheels and cams to draw the limbs back. The limbs of a compound bow are usually much stiffer than those of a recurve bow or longbow. This limb stiffness makes the compound bow more energy efficient than other bows, but the limbs are too stiff to be drawn comfortably with a string attached directly to them. The compound bow has the string attached to the pulleys, one or both of which has one or more cables attached to the opposite limb. When the string is drawn back, the string causes the pulleys to turn. This causes the pulleys to pull the cables, which in turn causes the limbs to bend and thus store energy. The use of this levering system gives the compound bow a chance to rise to a peek force when releasing the arrow but with only a slight force which is about 60 Newton to give force up to 260 Newton. The compound bow is slightly affected by changes of temperature and humidity but gives superior accuracy, speed, and distance in comparison with other bows (elyarchers, 2012).

2.3 COMPOSITE MATERIALS

2.3.1 Composites

According to Camphell (2010), a composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. Whereas, Roylance (2000) states that composite can be mean by everything since all materials composed of dissimilar subunits if examined at close enough detail.

Most composites have strong, stiff fibres in a matrix which is weaker and less stiff. The objective is usually to make a component which is strong and stiff, often with a low density. Commercial material commonly has glass or carbon fibres in matrices based on thermosetting polymers, such as epoxy or polyester resins.

Sometimes, thermoplastic polymers may be preferred, since they are mouldable after initial production. There are further classes of composite in which the matrix is a metal or a ceramic. For the most part, these are still in a developmental stage, with problems of high manufacturing costs yet to be overcome. Furthermore, in these composites the reasons for adding the fibres are often rather complex. This software package covers simple mechanics concepts of stiffness and strength, which, while applicable to all composites, are often more relevant to fibre-reinforced polymers.

2.3.2 Characteristics of composite materials

Composites materials are well known for its better qualities compared to other single materials. Normally composite materials have high specific strength and modulus which allows them to withstand high impact together high fatigue strength and fatigue damage tolerance. Composites can also be told as anistropic due to its property which is directionally dependent. Besides that, composites also have some extra properties such as designable or tailor able materials for both microstructure and properties, production of both material and structure or component in a single operation such as manufacturing flexible, net-shape, complex geometry and also known for its corrosion resistance and durable properties (Gou, 2012).

2.3.3 Reinforcements

Reinforcements comprises of fibrous materials used to strengthen cured resin system. The most common reinforcements are glass, carbon, aramid and boron fibres. The reinforced material that is widely used for archery purpose is aluminium and fibreglass.

2.3.3.1 Fibreglass

Fibreglass is widely use in composite materials. Fiberglas is material made from extremely fine fibres of glass. It is used as a reinforcing agent for many plastic products. The fibreglass ingredients are silicon oxide with addition of small amounts of other oxides. Glass fibre is formed when thin strands of silica based or other formulation glass is extruded into many fibres with small diameters suitable for textile processing. Glass is unlike other polymers in that, even as a fibre, it has little crystalline structure. The properties of the structure of glass in its softened stage are very much like its properties when spun into fibre. One definition of glass is an inorganic substance in a condition which is continuous with, and analogous to the liquid state of that substance, but which, as a result of a reversible change in viscosity during cooling, has attained so high a degree of viscosity as to be for all practical purposes rigid. Fibreglass is widely use because of its desirable characteristic such as high strength, good temperature and corrosion resistance, and low price (Salleh, 2006).

Nowadays, many types of fibreglass could be found. Each fibreglass has its own properties and benefits. Table 2.1 shows few types of fibreglass which is commonly found and the properties of the each fibreglass.

Table 2.1: Fibreglass and its properties

Fibreglass	Properties
A-glass	Made up of soda lime silicate glasses used where the strength, durability, and good electrical resistivity needed.
C-glass	Made up from calcium borosilicate glasses used for chemical stability in corrosive acid environments.
D-glass	Made up from borosilicate glasses with a low dielectric constant for electrical applications.
E-glass	Made up from Alumina-calcium-borosilicate glasses with a maximum alkali content used as general purpose fibres where strength and high electrical resistivity are required.
ECR-glass	Made up from calcium aluminosilicate glasses with a maximum alkali content used where strength, electrical resistivity, and acid corrosion resistance are desired.
AR-glass	Made up of alkali resistant glasses composed of alkali zirconium silicates used in cement substrates and concrete.
R-glass	Made up from calcium aluminosilicate glasses used for reinforcement where added strength and acid corrosion resistance are required.
S2-glass	Made from magnesium aluminosilicate glasses used for textile substrates or reinforcement in composite structural applications which require high strength, modulus, and stability under extreme temperature and corrosive environments.

Source: Hartman, Greenwood and Miller (1996)